5-11-1979

Noise reduction by multiple image printing

William McDonnell

NOISE REDUCTION

BY

MULTIPLE IMAGE PRINTING

by

William McDonnell

A thesis submitted in partial fulfillment of the requirements for the degree of Bachelor of Science in the School of Photographic Arts and Sciences in the College of Graphic Arts and Photography of the Rochester Institute of Technology

Advisor

Prof. Mohamed F. Abouelata

May 11, 1979

6 - 925591

ABSTRACT

A method of noise reduction by the successive partial printings of identical negatives was investigated. Image enhancement in terms of granularity reduction and resolution increase was obtained.

INTRODUCTION

The ability of a film to record fine detail is ultimately limited by the granularity of the emulsion. If a greater recording capacity is required it is usually necessary to use an extremely fine grained emulsion. However, considerations of photographic speed, contrast, availability, and cost may make this impractical, if not impossible. In 1947, Stevens[1] reported on a comprehensive study to reduce graininess based on suggestions by Hickman[2]. A negative superimposition technique, which involves making successive partial printings of optically identical negatives onto a single piece of print material, not only resulted in reduced graininess, but also in increased resolution. Using eight negatives, Stevens achieved a reduction in graininess by about one-third, and an increase in resolution from 20 to 60 percent. The resolution improvement was greater for lower contrast image detail.

In light of the present understanding of the nature of graininess and its quantitative measure called granularity, the following explanation for this image enhancement is presented. For a multiple image print made from the successive partial exposures of N identical negatives(identical here means the same image detail on the same type of film), the grain distribution is the result of the combination of N grain distributions each with the same standard deviation of density fluctuation(granularity). Provided that each negative is exposed so that it contributes equal density, then to a first approximation the granularity of the composite print is inversely proportional to the square root of N(see appendix). The reduced noise will result in an increased signal to noise ratio. If the negatives are printed in exact register, increased information capacity and resolution would be expected.

In 1963, Kohler and Howell[3] investigated the use of multiple image printing for aerial photography. For a combined printing of three negatives they found a reduction of granularity of 35 percent and a similar increase in resolution. Once again, the resolution increase was greater for lower contrast images.

Multiple image printing has also been used extensively with astronomical photography.[4] In 1959, Johnson[5] combined ten images of a star field to produce a composite print that yielded stars 1.2 magnitudes fainter than that of the individual images(magnitude is a measure of the apparent brightness of a star[6]). Additional details of using this method for stellar enhancement are described by Baum[7], Bowen[8], and Racine[9,10]. Applications to planetary photography have been described by Lyot[11], Kuiper and Calvert[12], and Kirby[13]. Wallis and Provin[14], and Hudgins[15] have illustrated the method for use by amateur astronomers to enhance their own astro- -photographs.

The purpose of this research was to investigate the technique of multiple image printing. In peticular, to produce multiple image prints from which granularity(noise) and resolution could be measured as a function of the number of negatives used to make the multiple image print.

EXPERIMENTAL

The production of multiple image prints that would answer the objectives required a sturdy projection printer, negative and print photographic materials, a test target from which resolution and granularity could be measured, a method for registering the negatives, the determination of proper printing exposures, and a microdensitometer for granularity measurements.

Enlarger and Film Materials

A Simmon Omega D-2 enlarger with a 50mm f/4.5 Kodak Ektor enlarging lens was selected for sturdiness, availability, and adaptability to floor projection. Kodak film type Plus-X Pan was selected as the negative material because it has medium grain and resolving power and common availability. Films with extreme resolution and fine grain would necessitate very high printing magnifications. Kodak film type Commerical 6127 (4x5 inch format) was selected as a print material that would not contribute noise to the system. In addition, it was usable with safelight illumination.

Test Target

A test target was made consisting of three 8x8 inch RIT alphamumeric resolution targets with density contrasts of

1.3, 0.7, and 0.2, a Kodak gray scale, and an 18 percent gray card. The gray card provided an area of uniform density on the print transparencies for granularity determination. The gray scale was originally intended to permit measurement of print contrast, but this was later considered unimportant. However, image detail of the gray scale was used to assist in negative registration.

A Konica Autoreflex T 35mm camera with a 50mm f/1.8 Konica Hexagon lens was used to image the target onto the Plus-X film at a reduction of 84.8 times. This reduction was selected for the following reasons: 1) The largest characters on the resolution targets must be resolved. 2) The target image at the print exposing plane must fit within the 4x5 inch format, yet the degree of enlargement had to be enough for the Plus-X grain to become apparent.

Negative Registration

Stevens used pin registration to align each negative of a series of cinematograph images. However, pin registration was considered too restrictive since the image may not be precisely in the same location within successive negative frames. Wallis and Provin suggest using a pencil to mark image details from the first negative on white cardboard attached to the printing easel cover, and then visually aligning the corresponding image detail from successive negatives to these marks. While this method may work well for the star images that Wallis and Provin used to illustrate multiple image

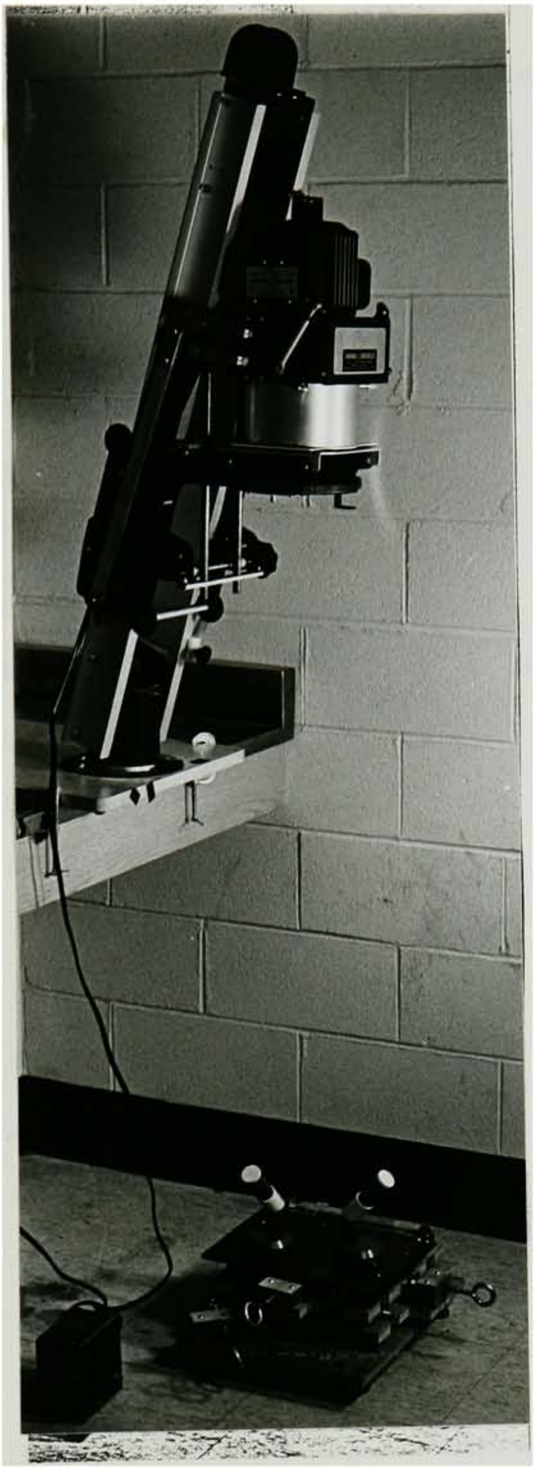


Fig. 1. The printing set-up.

printing, it was considered too crude for the test target images and for conventional images as well.

A special registration device, as shown in Fig. 1 at the exposing plane of the Simmon Omega enlarger, was designed and built to achieve negative alignment in a manner similar to that suggested by Wallis and Provin. The crosshairs in two Patterson brand image finders are used for alignment reference instead of pencil marks.

Fig. 2 illustrates the optical function of a Patterson image finder. Image detail that would otherwise focus on the exposing plane is focused on a crosshair in the tube of the image finder via reflection from a plane mirror. An eyepiece provides a 12X magnification of this image detail and crosshair together.

Figs. 3a and 3b are close-ups of the registration device. Magnets were installed in the base of each image finder to hold them secure to a thin, lightweight steel cover plate mounted to an exposing plane cover. The cover prevents exposure to the print material during registration. Selected image detail from the first negative to be exposed is aligned to the finder crosshairs by hand adjustment of the finders about the cover. When the cover is raised to make an exposure, the finders remain secure (Fig. 3b). Corresponding image detail in successive

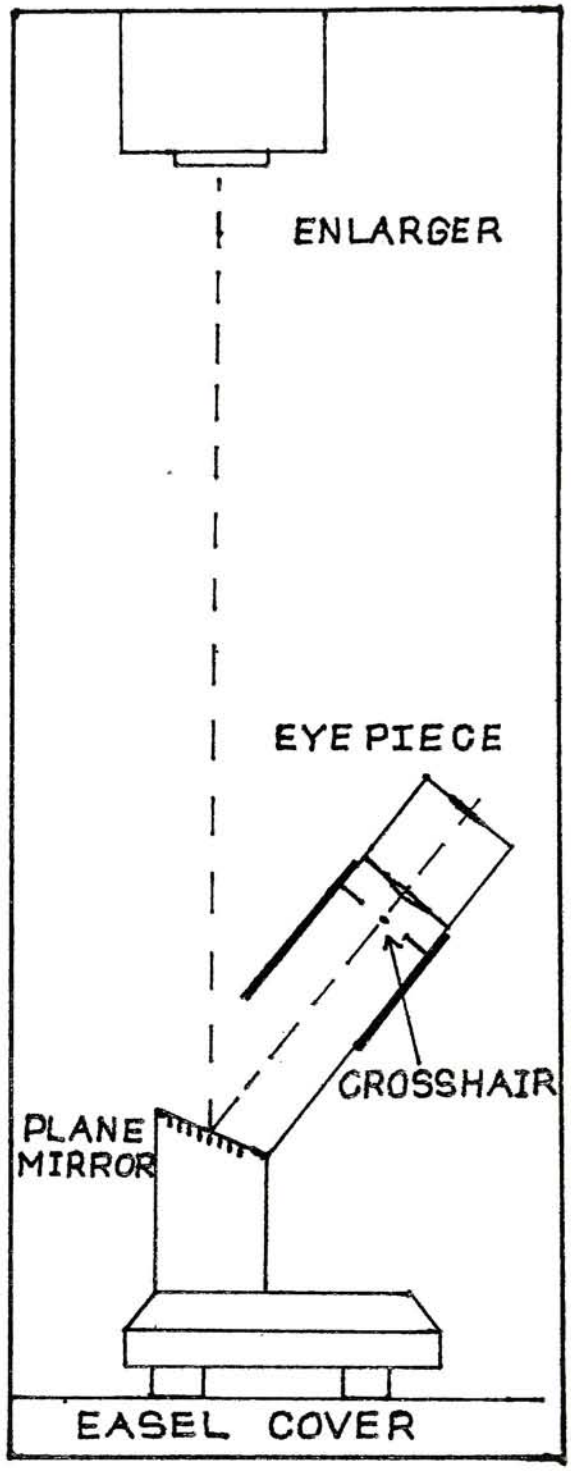
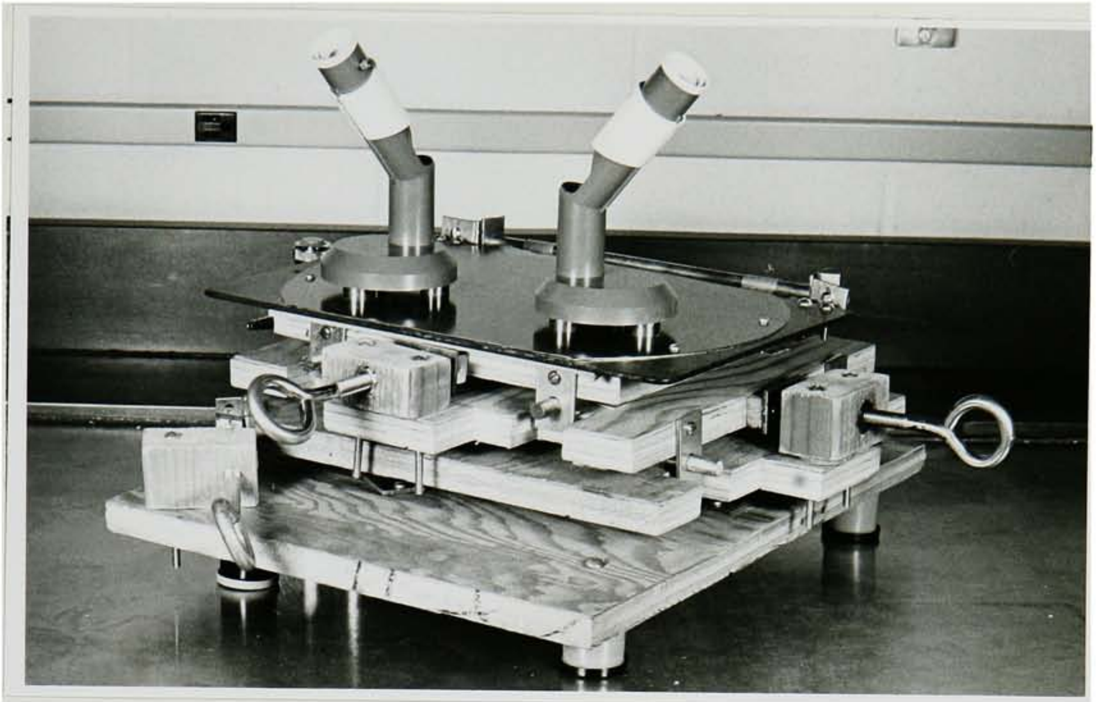
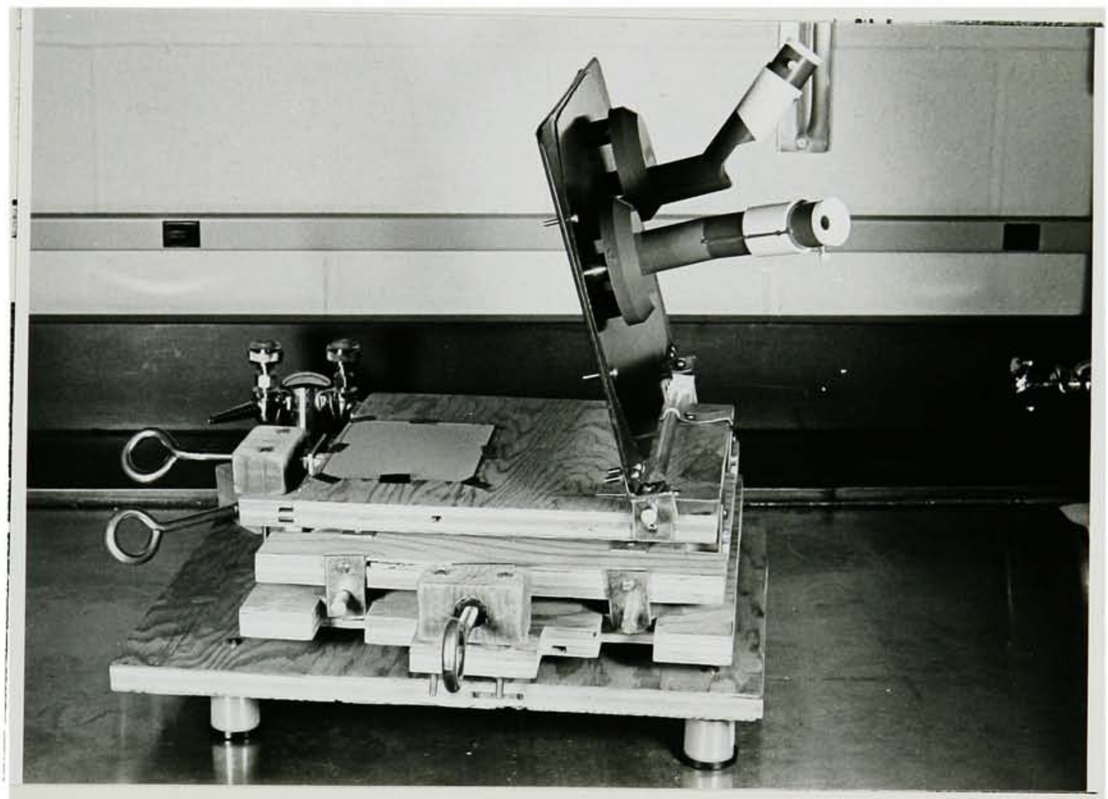


Fig. 2. Optical function of Patterson image finder.



(a)



(b)

Fig. 3. The registration device.

negatives is aligned to the finder crosshairs using three precision movements which adjust the position of the exposing plane. One circular and two perpendicular straight motions are provided by three independantly moving stacked carriages. The bottom carriage moves circularly about a centrally located 1½ inch diameter steel tube. It rides on the heads of three ¼ inch bolts which rest on three 3x1x1/8 inch steel strips attached to the base. The middle and top carriage move straight by riding on two 3/8 inch steel rods. Three-eighth inch holes drilled in four 2x1x1/8 inch steel strips securely attach the carriages to the rods permitting motion only in the intended direction. The movements of all three carriages are controlled by 3/8 inch diameter bolts with sixteen threads per inch. A 1/32 bolt revolution provides a precision movement of 0.05mm with no detectable backlash.

Printing Exposures

It was desired that each negative involved in making a multiple image print contribute equal density. Thus, when determining printing exposure times for individual negatives, the effects of the non-linearity between exposure time and density, the intermittency effect, and the reciprocity law failure of the print material must be considered. In addition, the total exposure time(the correct exposure if printing only one negative)must be long enough so that individual exposures can be accurately made.

The Simmon Omega enlarger was adjusted to a printing magnification(25.8X)so that the test target filled the 4x5 inch format. An exposure time series ranging from two to 160 seconds was made using the Kodak Commercial film 6127. Gray card image density was plotted as a function of exposure time. This curve permitted calculation of equal density exposures using any mumber of negatives. It was decided to make multiple image prints using 1,2,4, and 8 of the Plus-X negatives based on a total exposure time of 100 seconds at f/11. Samples were made using intermittent exposures as calculated for each of these numbers of negatives. The resulting gray card image densities were within 0.03 of 1.66 indicating no significant density variation due to the intermittency effect.

Two sets of the four multiple image prints were made. The gray card images were scanned with an Ansco Model 4 automatic recording microdensitometer. For each print transparency, approximately 500 independent density values were used to determine the granularity. Resolution was determined by visually examining the transparencies with a slide illuminator. The images of the RIT alphanumeric targets were evaluated by determining the smallest row in which all three characters could be identified.

RESULTS AND DISCUSSION

Table 1. Granularity and resolution of individual print sets.

Negatives Printed	Standard Deviation of Density Fluctuation(90% confidence)		Resolution(set1,set2) (line pairs/mm			
	Set 1	Set 2	ΔD	1.3	0.7	0.2
1	2.85-3.15	2.73-3.03		30,30	27,27	24,21
2	2.05-2.28	2.11-2.37		30,30	30,27	24,24
4	1.45-1.62	1.49-1.66		34,30	30,30	27,27
8	0.99-1.10	1.08-1.20		34,34	30,30	30,30

Table 1 shows resolution and the standard deviation of density fluctuation as determined for each multiple image print set. For the values of the standard deviation of density fluctuation, the confidence interval arises from the statistical limitation when determining actual values from a finite sample of measured print densities.[16] The true value has a 90 percent probability of being between the values indicated. An F-test between corresponding prints in the two sets indicated that each was an estimate of the same actual standard deviation of density fluctuation.

Table 2. Pooled granularity and average resolution.

Negatives Printed	Normalized and Pooled Granularity(90% conf.)	Average resolution(lps/mm) ΔD	1.3	0.7	0.2
1	0.96-1.04		30	27	22
2	0.72-0.78		30	28	24
4	0.51-0.55		32	30	27
8	0.36-0.39		34	30	30

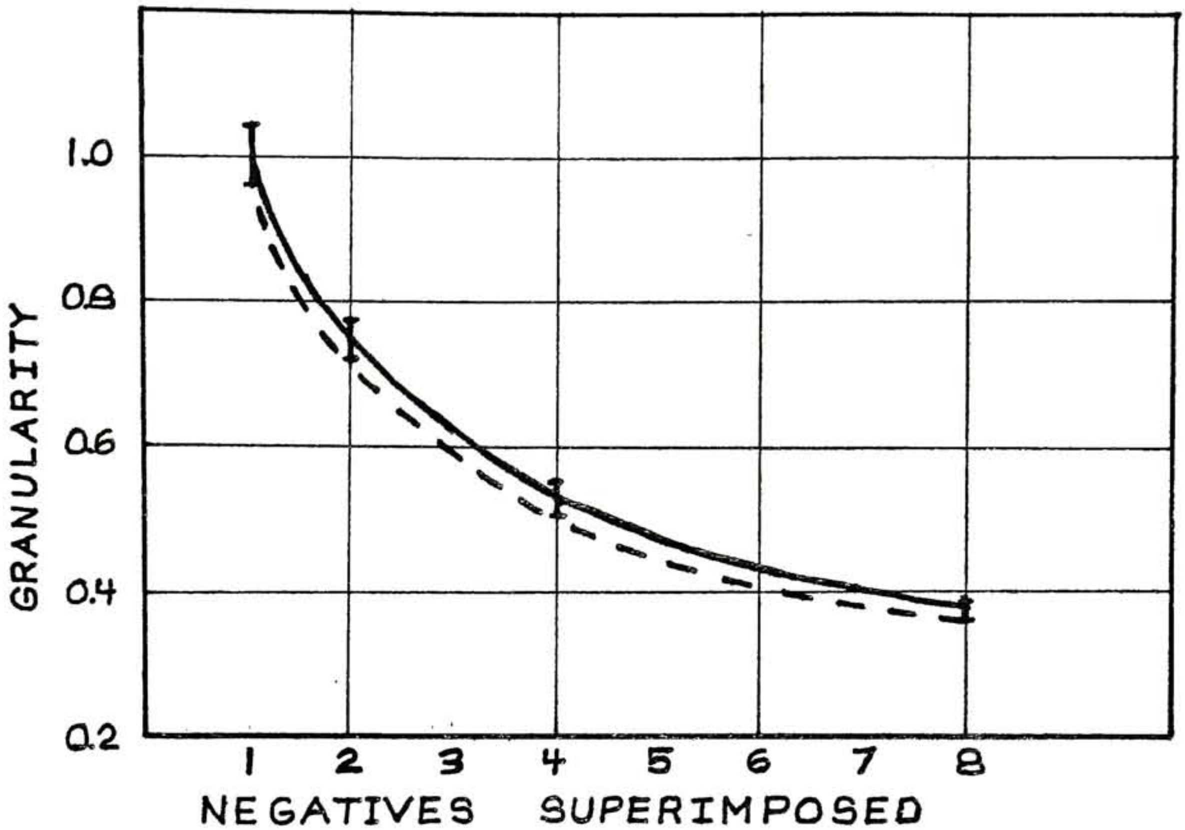


Fig. 4. Granularity as a function of number of negatives superimposed. The dotted line is the predicted curve.

Table 2 shows granularity as the pooled standard deviation of density fluctuation between sets 1 and 2 which has been normalized to 1.00 for the single negative prints. The resolution is the average of the two sets. These results are plotted in Figs. 4 and 5.

Fig. 4 shows granularity as a function of the number of negatives combined. Hash marks represent the 90 percent confidence intervals. The dotted curve is the expected inverse square root relationship beginning at 1.00 for the single

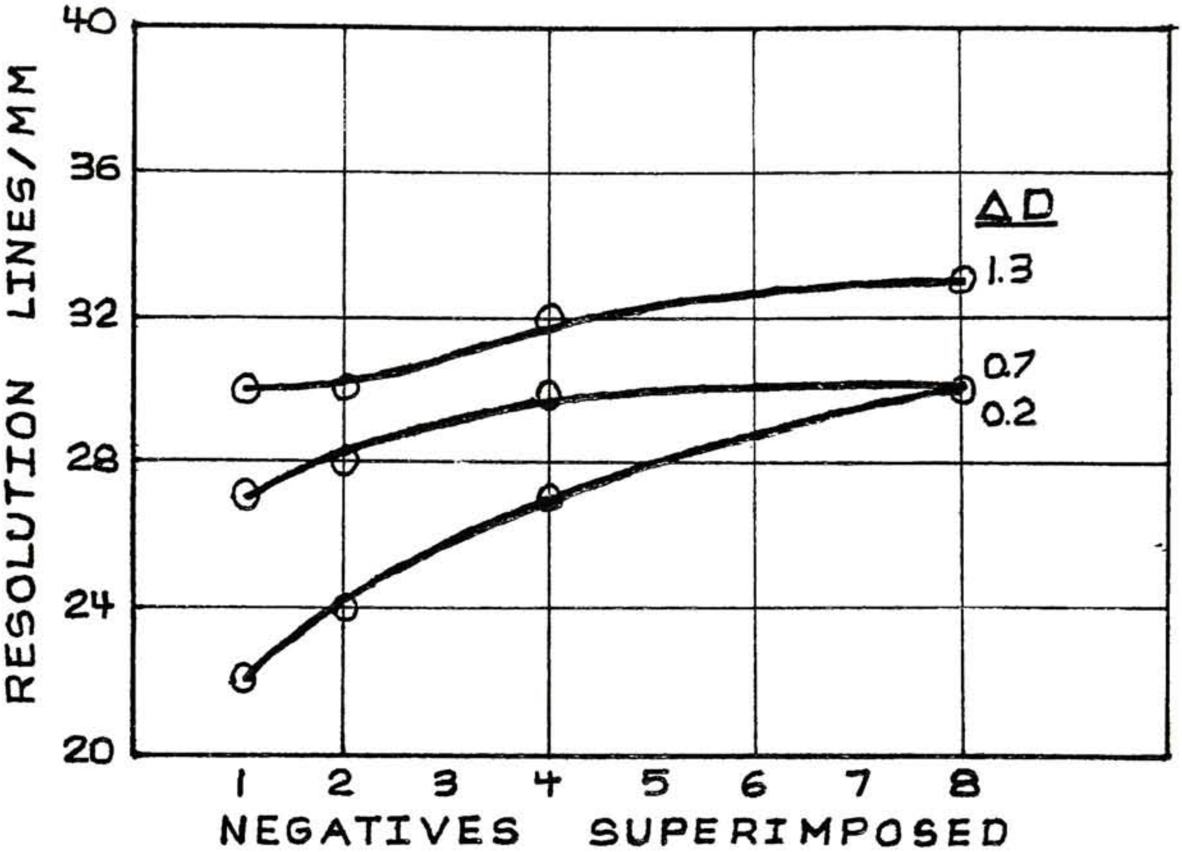


Fig. 5. Resolution as a function of the number of negatives superimposed for target density contrasts of 1.3, 0.7, and 0.2.

negative print. Considering the confidence intervals, the experimental curve appears to agree with the expected curve. Thus, the inverse square root relationship between granularity and number of negatives superimposed is a good predictor of the noise reduction obtained by the process.

Fig. 5 shows resolution as a function of the number of negatives combined for the three target contrast levels. For all three levels, the resolution increases most rapidly when one to four negatives are used. Superimposing more than eight negatives would not be expected to increase resolution enough to warrant the additional time and effort required for most applications. The superimposition of eight negatives resulted in a 13 percent high contrast resolution increase and a 27 percent low contrast resolution increase. The resolution difference between the high and low contrast resolution dropped from eight to four lines per millimeter. One explanation for this is that the low contrast resolution is influenced less by negative registration errors because it is smaller to begin with. Thus, multiple image printing could be used to enhance shadow detail of conventional photographic images.

CONCLUSIONS

Multiple image printing will provide a useful reduction in grain(noise) and an increase in resolution if the problems of negative registration and exposure can be overcome. Present applications are subject to whether the time and effort involved justifies the amount of image enhancement obtained. Considering the constant improvement of photographic materials, electronic imaging techniques, and computer enhancement techniques, it seems unlikely that multiple image printing will ever increase in application. Yet it will remain available for use by those who find it to be just the thing they need.

REFERENCES

1. G.W.W. Stevens, "The Effect of Diffusion on the Graininess and Resolution Obtained From Processed Negatives", The Photographic Journal, Vol. 87B, pps. 74-80.(1947)

2. K.C.D. Hickman, J.S.M.P.E., Vol. 10, pg. 49. (1926)

3. R.J. Kohler and H.K. Howell, "Photographic Image Enhancement by Superimposition of Multiple Images", Photographic Science and Engineering, Vol. 7, pps. 241-245. (1963)

4. A.A. Hoag and W.C. Miller, "Application of Photographic Materials In Astronomy", Applied Optics, Vol. 8, No. 12 pps. 2417-2430. (1969)

5. H.L. Johnson, R.de F. Neville, and B. Iriarte, Lowell Observatory Bulletin, Vol. 4, p. 85. (1959)

6. J.A. Mauro, ed., Optical Engineering Handbook, General Electric, Sect. 11, pps. 39-40. (1957)

7. W.A. Baum, Astronomical Techniques, W.A. Hiltner,Ed. (University of Chicago Press, Chicago, 1962).

8. I.S. Bowen, Astronomical Journal, Vol. 69, p. 816 (1964)

9. R. Racine, Journal Royal Astronomical Society of Canada, Vol. 60, p. 52.(1966)

10. R. Racine, Astronomical Journal, Vol. 72, p. 65. (1967)

11. B. Lyot, L'Astronomie, Vol. 57, p. 67. (1943)

12. G.P. Kiuper and M.R. Calvert, Astrophysical Journal, Vol. 105, P. 215. (1947)

13. D.S. Kirby, Publ. Astron.Soc. Pacific, Vol. 71, p.334. (1959)

14. B.D. Wallis and R.W. Provin, "Integration Printing: An Aid to Long Exposure Astrophotography", Astronomy, Vol. 1, No. 3, pps. 35-39. (1973)

15. D. Hudgins, "Printing Your Astrophotographs-Part Four", Astronomy, Vol. 5, No. 12, pps. 34-39. (1977)

16. A.D. Rickmers and H.N. Todd, Statistics: An Introduction, McGraw-Hill(1967), pps. 108-124.

APPENDIX

Given a film sample A characterized by a density fluctuation due to the granularity of the emulsion, let D(A) be the average density and D(A)+d(Ai) be the density of any i^{th} spot in the emulsion where d(Ai) is the density difference between the i^{th} spot and the mean. The variance of the density fluctuation about the mean D(A) can then be defined as

$$\sigma_A^2 = \sum_{i=1}^{n} (D(A)+d(Ai) - D(A))^2/n = \sum_{i=1}^{n} d(Ai)^2/n$$

where n is the number of individual spot densities. Similarly, a film sample B has a variance of density fluctuation of

$$\sigma_B^2 = \sum_{i=1}^{n} d(Bi)^2/n$$

For the combination of film sample A and film sample B, the average density becomes(D(A)+D(B))/2 and the density of the i^{th} spot becomes (D(A)+d(Ai)+D(B)+d(Bi))/2. Thus, for the combination, the resulting variance of density fluctuation about the mean is,

$$\begin{aligned}\sigma_{AB}^2 &= \sum_{i=1}^{n} ((D(A)+D(B)+d(Ai)+d(Bi))/2 - (D(A)+D(B))/2)^2/n \\ &= \sum_{i=1}^{n} ((d(Ai)+d(Bi))/2)^2/n \\ &= \sum_{i=1}^{n} ((d(Ai)^2/4n)+(d(Bi)^2/4n)+(d(Ai)d(Bi)/2n)) \\ &= \sigma_A^2/4 + \sigma_B^2/4 + \sum_{i=1}^{n} (d(Ai)d(Bi)/2n)\end{aligned}$$

To a first approximation, the third term above can be neglected. In addition, if film sample A and film sample B are samples of the same type of film, then $\sigma_A^2 = \sigma_B^2$ and

$$\sigma_{AB}^2 = \sigma_A^2/2$$

The standard deviation of the density fluctuation is then

$$\sigma_{AB} = \sqrt{\sigma_A^2/2} = \sigma_A/\sqrt{2}$$

Thus a composite print made from two identical negatives has a granularity reduction of $\sqrt{2}$ as compared to the individual negatives.

It can similarly be shown that for the combination of N negatives, the granularity will reduce by a factor of $\sqrt{N}$. Hence,

$\sigma_N = \sigma_I/\sqrt{N}$ where σ_N is the granularity of a composite print made from N negatives and σ_I is the granularity of the individual negatives.